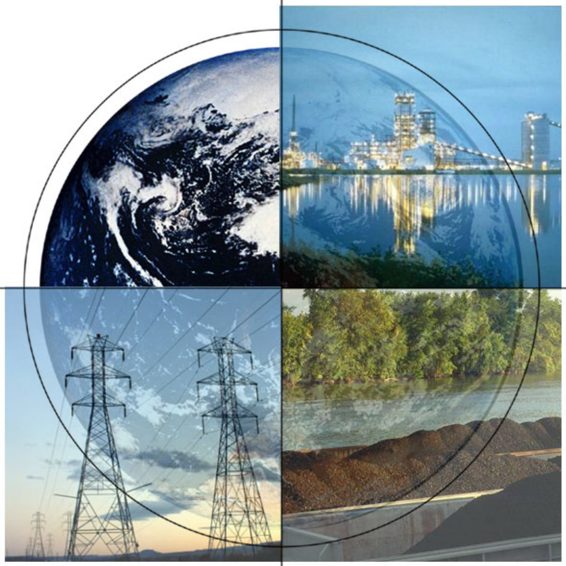
Hydrogen From Coal



Tutorial

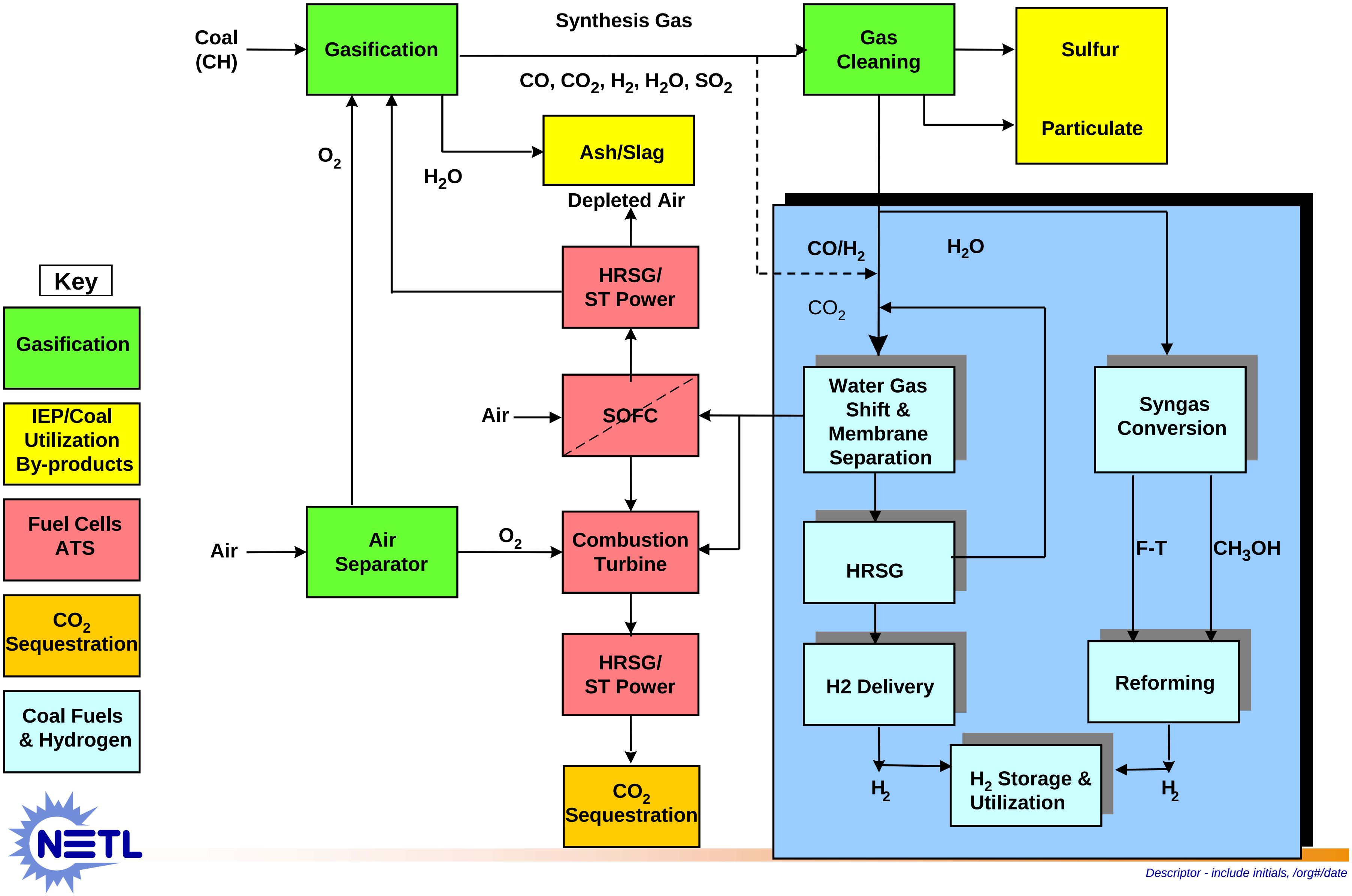
The Clearwater Conference

April 19, 2004

John C. Winslow, Technology Manager
National Energy Technology Laboratory

Clean Coal Fuels Technology Lines	Key Elements	Technology Outputs	Key Milestones
Transportation Fuels and Chemicals	*Coal Fuels*	*Hydrogen Production, storage and utilization*	*By 2010, hydrogen from coal can be produced for $30/bbl oil equivalent*
Advanced Fuels Research	C1 Chemistry	Improved synthesis gas conversion	By 2010, technology base enables coal liquid fuels to be produced at $30/bbl oil equivalent via coproduction w/ power
Solid Fuels and Feedstocks	Coal-Derived Carbon Materials Separations	Premium Carbon Products/ Coal Fines Recovery	By 2010, separation technologies permit higher coal recovery at less cost; high value carbon products enter the market

Hydrogen From Coal
Program Components --- Technology Areas



Hydrogen Production Options

Sources of Hydrogen

Fossil Fuels with Sequestration

Water

Biomass

The U.S. uses 14MM BPD of oil for transportation

14MM BPD = 220MM TPY of H2 at current efficiencies

Increasing annual coal production by 33% (330MM tons) would provide 50MMTPY of H2

50MM TPY of H2 = 50% of our current transportation requirements at Freedom Car efficiencies

Sources of Heat to Drive Reaction

Nuclear Power

Renewables

Dream Source

- **Fusion**
- **Thermochemical**
- **Photochemical**

Biomass photo: NREL, Calvert Cliffs Nuclear Plant

Hydrogen Production…How important is Coal?

The National Academy of Engineering recently completed a year long study of: "The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs"

Key Findings…General and those specific to coal:

- Hydrogen could fundamentally transform the U.S. energy system; therefore a robust, ongoing hydrogen program is important
- Fossil Fuels will be one of the principal sources of hydrogen for the hydrogen economy…but carbon capture and storage technologies will be required
- The U.S. has vast coal resources…hydrogen from coal can be inexpensive…and…coal must be a significant component of R&D aimed at making very large amounts of hydrogen.

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Introduction

- **The U.S. has a 250-year supply of coal at present annual use**

- **A small number of chemical plants use coal to produce hydrogen via partial oxidation**

- **Eastman Chemical gasifies coal to produce methanol for chemical manufacturing; methanol could also be used as a near-term source of hydrogen….now fueling Georgetown University fuel cell buses.**

However -

- **At present, no facilities based on modern coal gasification have been constructed that produce both hydrogen and power….the lowest cost path for producing hydrogen**

Hydrogen From Coal: Goal

Facilitate the transition to a sustainable hydrogen economy through the use of coal, our largest domestic fossil resource

Objectives

•***Production: Central Pathway***
--- By 2015, demonstrate a 60% efficient , zero emissions, coal-fueled hydrogen and power co-production facility that reduces the cost of hydrogen by 25% compared to current coal-based technology

• ***Production: Hydrocarbon Pathway***
--- By 2010, complete tests and evaluations of most promising hydrogen-rich, coal-derived liquids for reforming applications

• ***Storage***
--- By 2015, work with other DOE Offices to develop safe, affordable technology capable of storing 9 wt. % hydrogen

• **Utilization**
--- By 2010, complete tests & evaluations of H2/natural gas mixtures in modified and advanced internal combustion engines

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Key Components: Hydrogen from Coal

- **R&D Areas & Technical Hurdles**
  - ***Production***: H_2 separation; liquid fuels development
    - S-poisoning; catalyst-reactor, catalyst/wax separation
  - **Storage**
    - H_2/CH_4 mixtures, materials/processes for high wt.% H_2 storage
  - ***Utilization:*** H_2/natural gas combustion in ICEs
    - Performance and emissions control
  - ***Process Engineering:*** Intensification
    - Combine processes to increase efficiency/reduce capital cost

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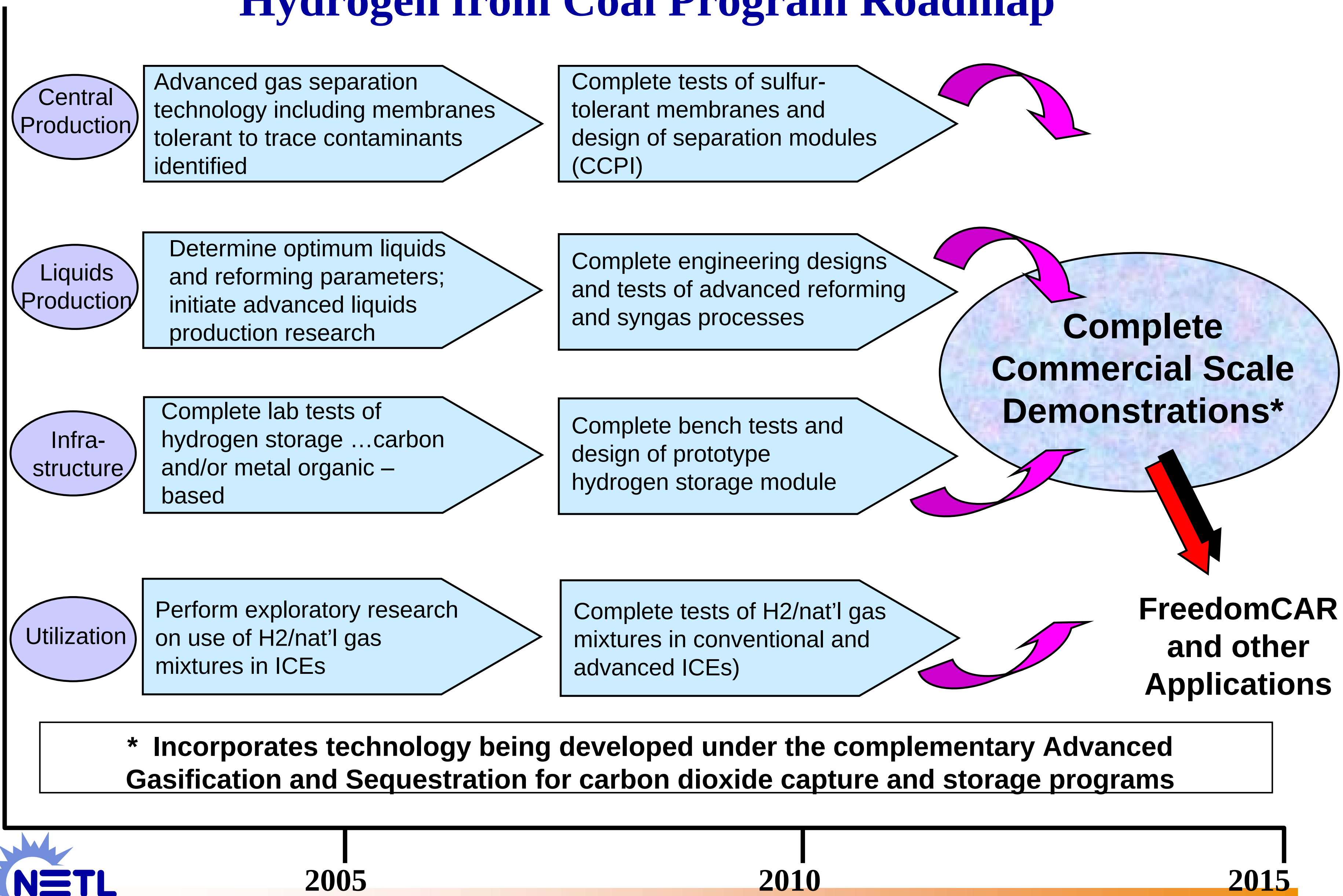
Hydrogen from Coal Program Roadmap



History of Gasification

- Used during World War II to convert coal into transportation fuels (Fischer – Tropsch)
- Used extensively in the last 50+ years to convert coal and heavy oil into hydrogen – for the production of ammonia/urea fertilizer
- Chemical industry (1960's)
- Refinery industry (1980's)
- Global power industry (Today)

Coal Gasification Can "Polygenerate" Many Products

Coal

Power

- **Electricity**
- **Steam**

Fuels

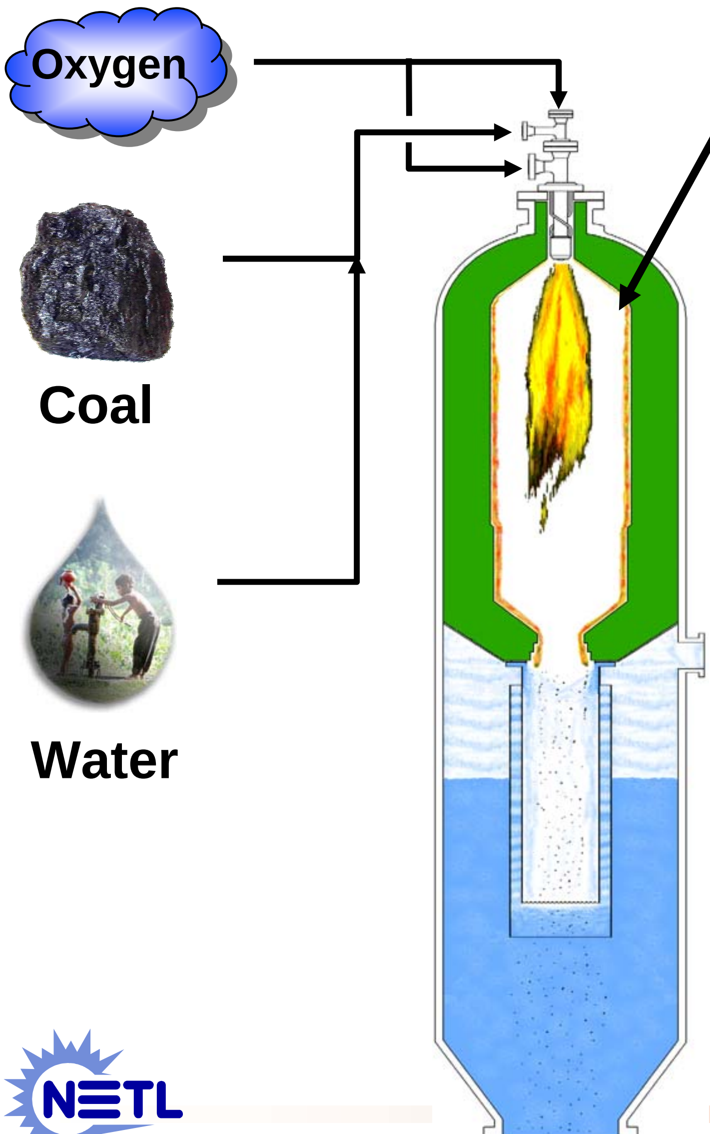
- **Fischer-Tropsch Diesel**
- **Naphtha**
- **Methanol**
- **Dimethyl Ether *AND***
- **Hydrogen**

Chemicals

- **Waxes**
- **Olefins**
- **Acetates and many Others**

Gasification Basics

(Courtesy of Eastman Chemical)



Extreme Conditions:

- Up to 1,000 psig or more
- Nominal 2,600 Deg F
- Corrosive slag and H_2S gas

Products:

CO (Carbon Monoxide)

H_2 (Hydrogen)

By-products:

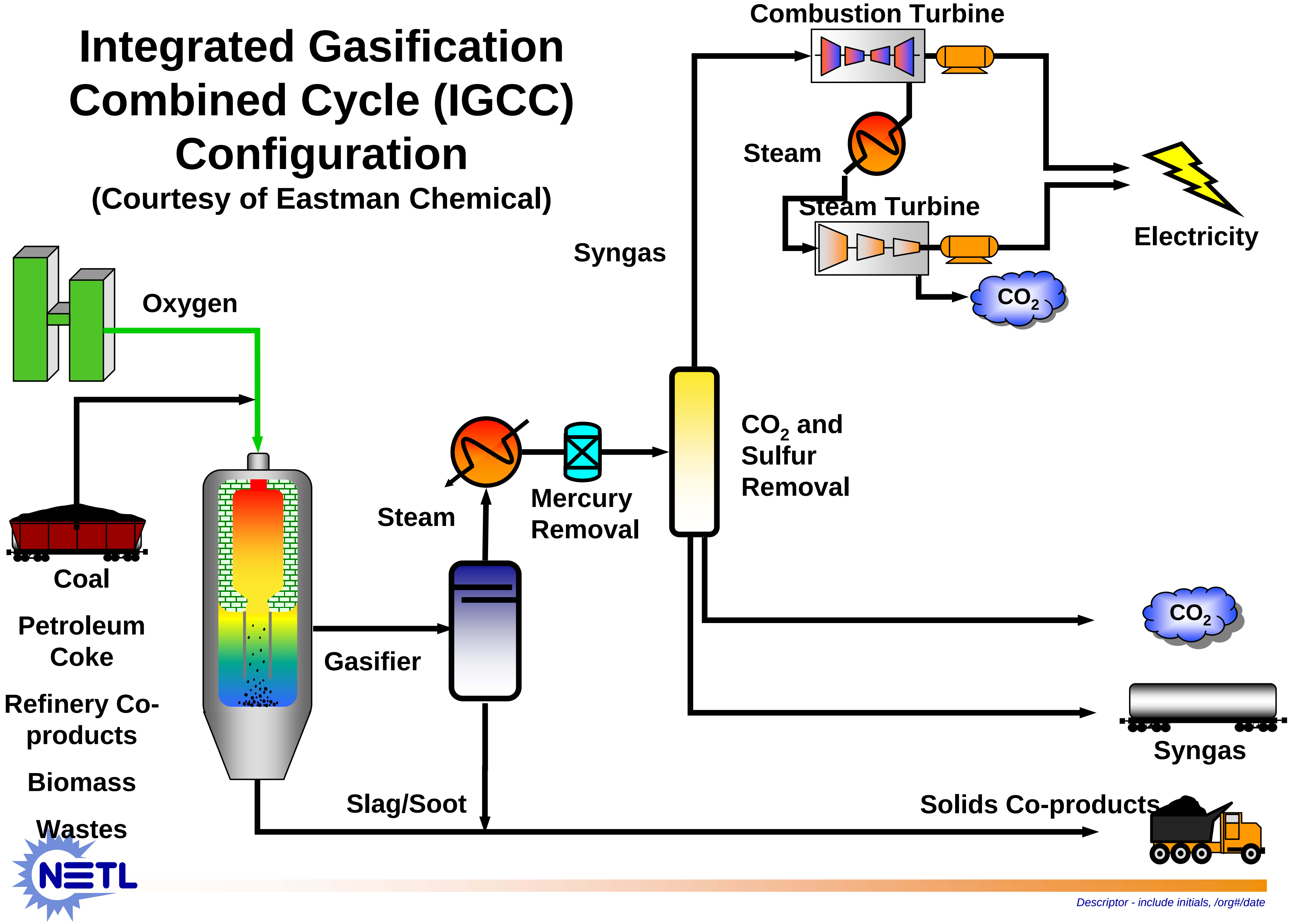
H_2S (Hydrogen Sulfide)

CO_2 (Carbon Dioxide)

Slag (Minerals from coal)

Integrated Gasification Combined Cycle (IGCC) Configuration

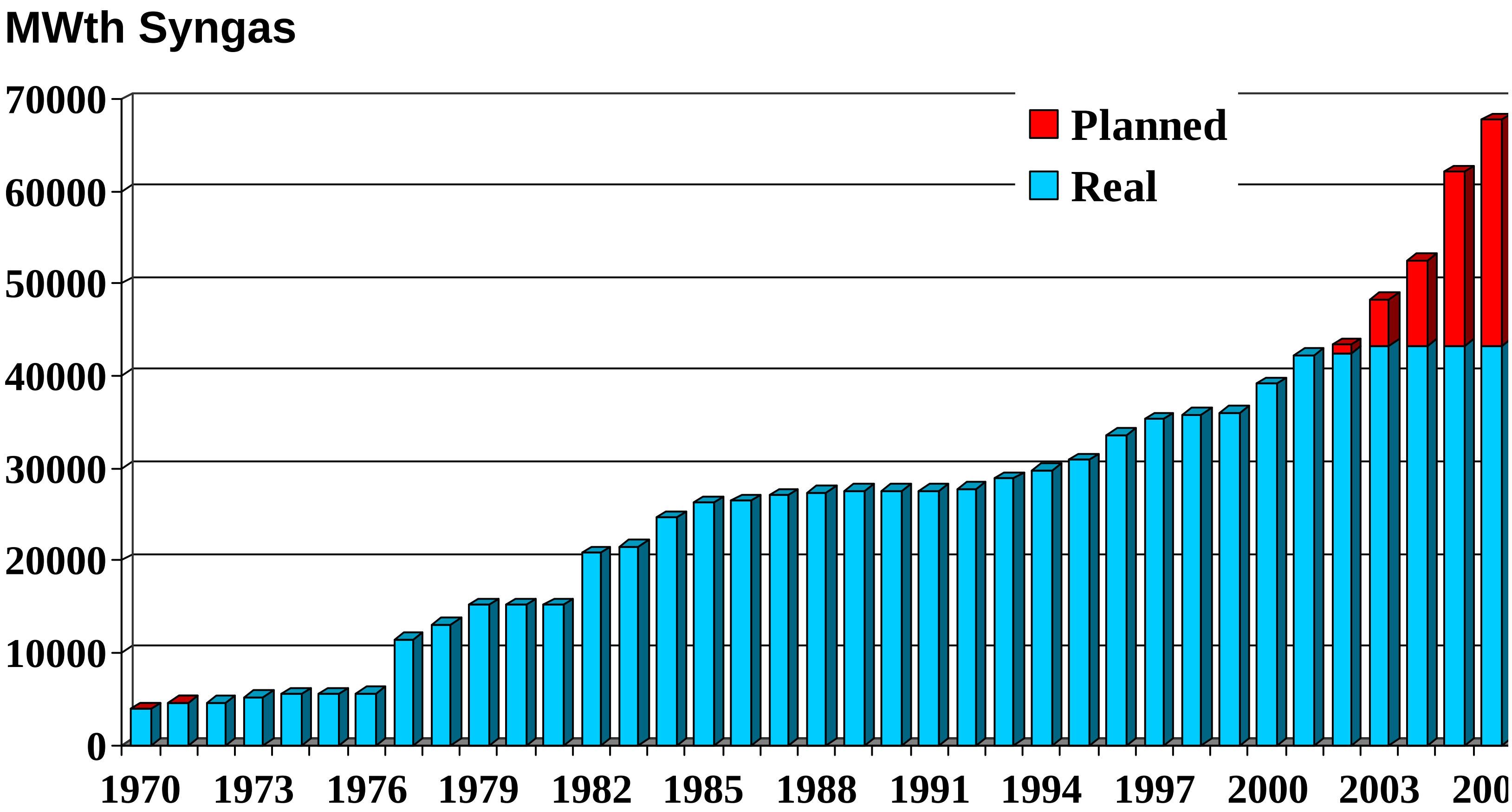
(Courtesy of Eastman Chemical)



Major Gasification Milestone

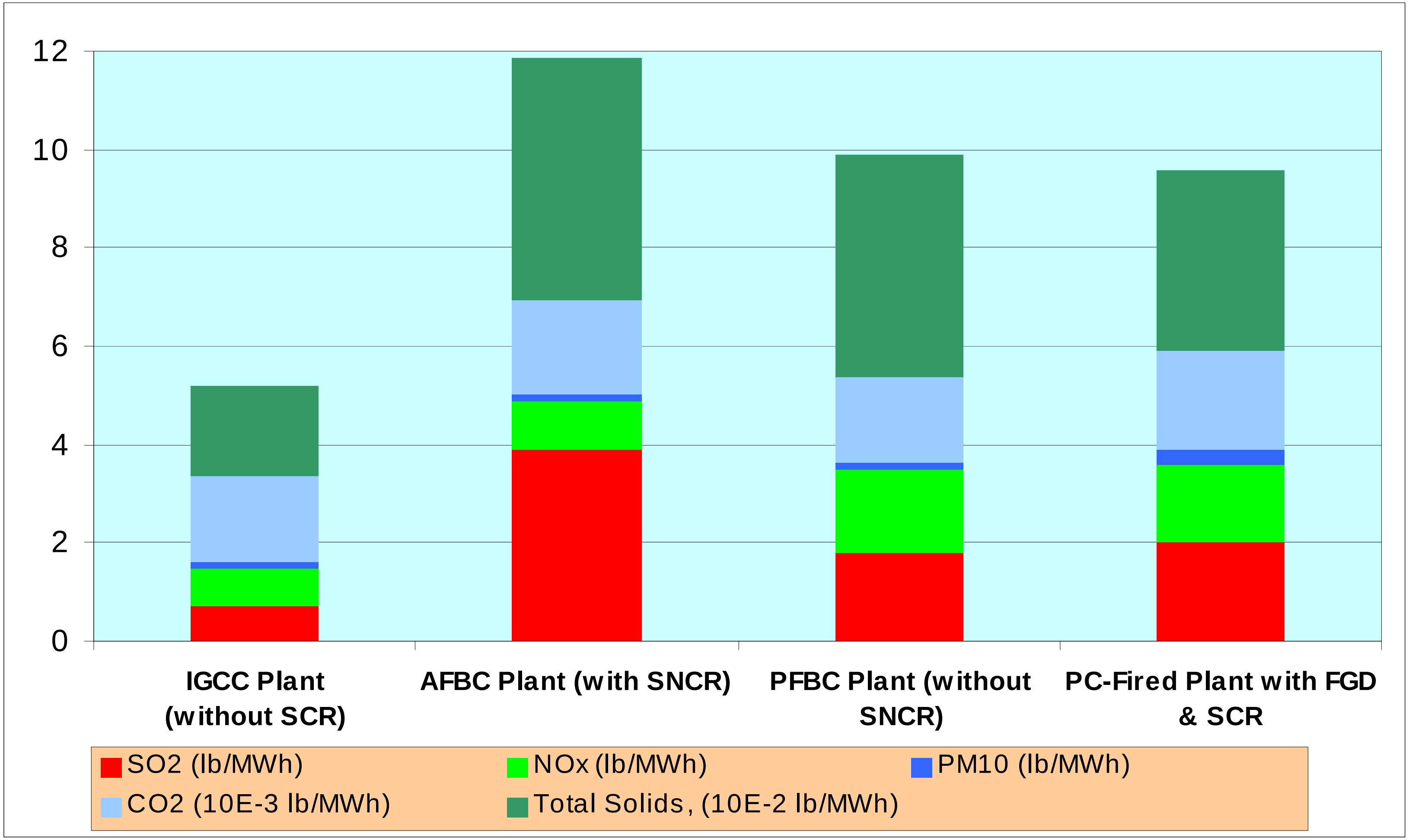
1842	Baltimore Electric Town Gas
1887	Lurgi Gasification Patent
1910	Coal Gasification Common in U.S. / Europe for Town Gas
1940	Gasification of Nature Gas for Hydrogen in the Chemical Industry (Ammonia)
1950	Gasification of Coal for Fischer-Tropsch (F-T) Liquids (Sasol-Sasolburg)
1960	Coal Tested as Fuel for Gas Turbines (Direct Firing)
1970's	IGCC Studies by U.S. DOE
1970	Gasification of Oil for Hydrogen in the Refining Industry
1983	Gasification of Coal to Chemicals Plant (Eastman Chemical)
1984	First Coal IGCC Demonstration (Coolwater Plant)
1990's	First Non-Recourse Project Financed Oil IGCC Projects (Italy)
1993	First Natural Gas Gasification F-T Project (Shell Bintulu)
1994	NUON/Demkolec's 253 MWe Buggenum Plant Begins Operation
1995	PSI Wabash, Indiana Coal IGCC Begins Operation (DOE CCT IV)
1996	Tampa Electric Polk Coal IGCC Begins Operation (DOE CCT III)
1997	First Oil Hydrogen/IGCC Plant Begin Operations (Shell Pernis)
1998	ELCOGAS 298 MWe Puertollano Plant
2003	WMPI IGCC "Polygeneration" Projected Selected (CCPI I)

Cumulative Worldwide Gasification Capacity and Growth

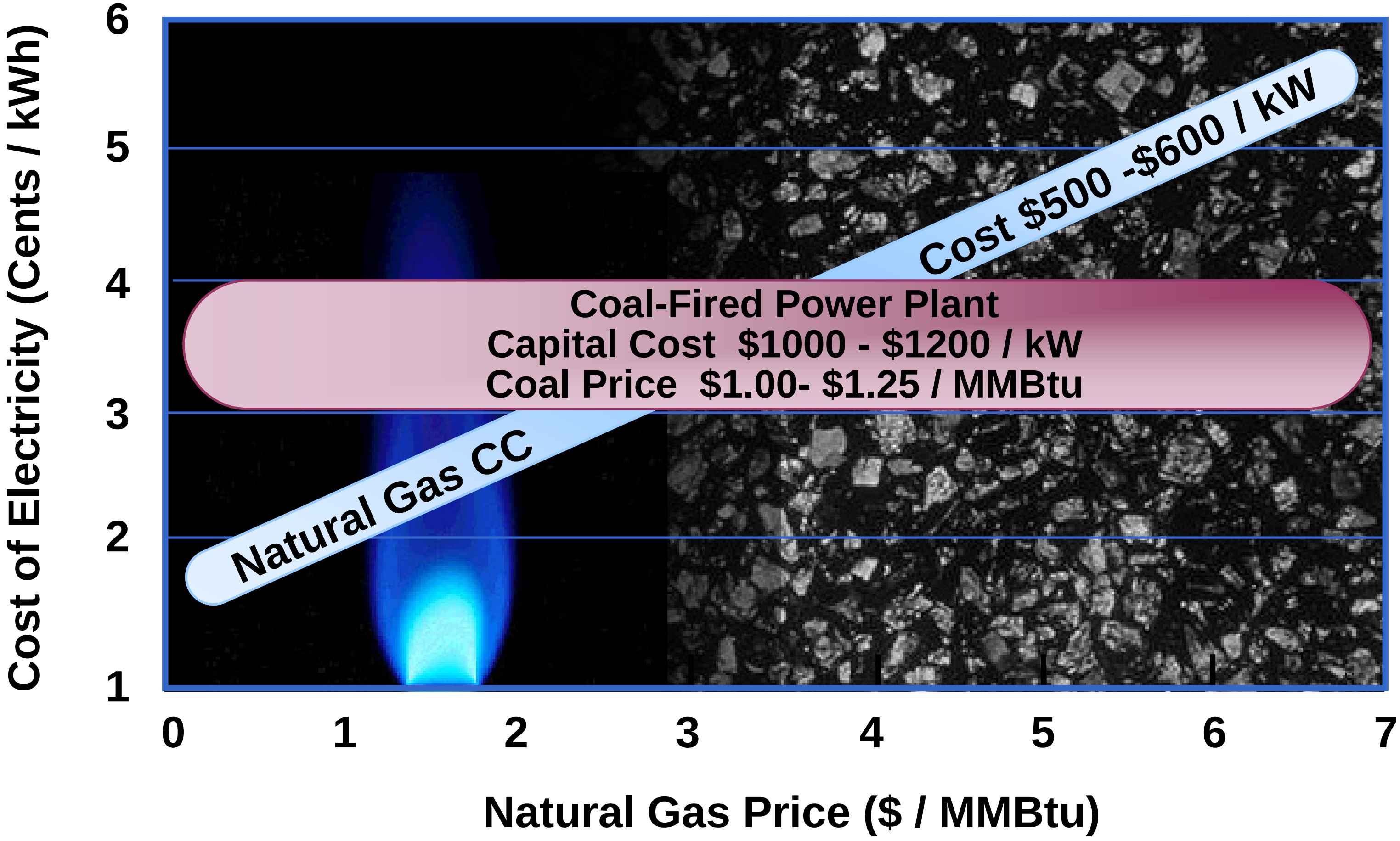


Source: SFA Pacific Gasification Database - 2001

Comparison of Emissions Between IGCC and Other Coal-Fired Technologies



New Coal Marginally Competitive with Gas



DOE Report #DE-AC-01-94FE62747, April 2001

Factors Affecting Gasification

- Favorable
  - High NG prices
  - Low quality feedstocks
  - Feedstock flexibility
  - Product flexibility/market matching
  - Ultra-clean fuels
  - Superior efficiency and environmental performance (requires monetization of benefits)
  - Potential of more exacting emissions regulations
- Unfavorable
  - Low NG prices (commodity market uncertainties)
  - Poor reliability
  - Uncertainties in environmental regulations
  - Lack of Investor confidence
  - Real/perceived risks
  - Project cost, size, and development time
  - Large footprint
  - Public perception of coal

Technology Hurdles

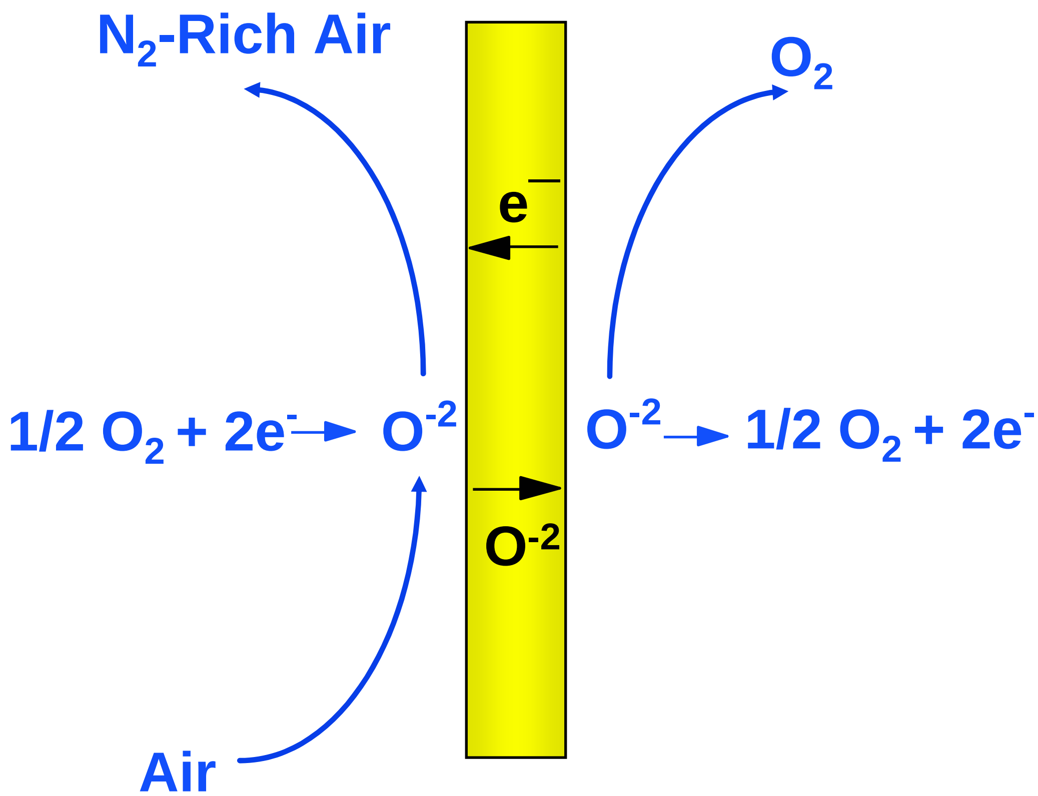
- Air Separation - Costly (12-15% of capital cost of IGCC) and inefficient (consumes 10% of gross plant power)

- Hydrogen Separation – Costly and inefficient for power applications

- Co-Production – Integration of power and fuels technologies

- CO2 Sequestration – Ensure the gas does not escape from the reservoir its stored in

Mixed-Conducting Oxygen Separation Membranes



Oxygen Conducting Membranes

- Pressure driven operation
- Mixed ionic - electronic conduction, no external circuit
- Oxygen ion transport through oxide materials
- Infinite O_2 selectivity
- High temperature process - 900 ºC

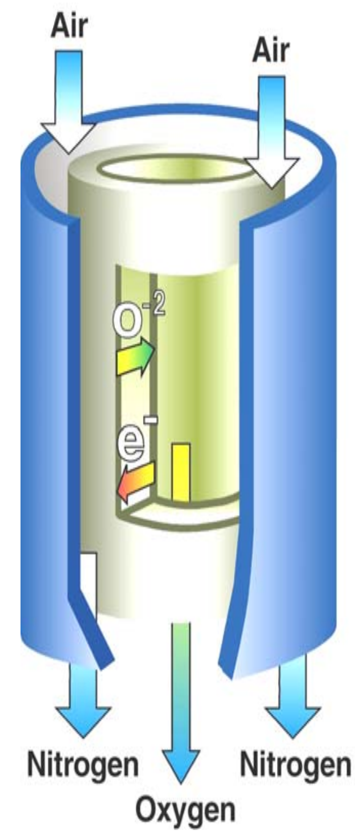
Example Scenario: Oxygen Separation

- Benefits of Oxygen Separation Membranes
  1. Lower capital cost than cryogenic oxygen systems
     - \$20,000 → \$13,000/tpd O_2 (35% decrease)[1]
  2. Lower auxiliary power
     - 235 kWh/ton O_2 → 147 kWh/ton O_2 (37% decrease)[1]

- Objectives

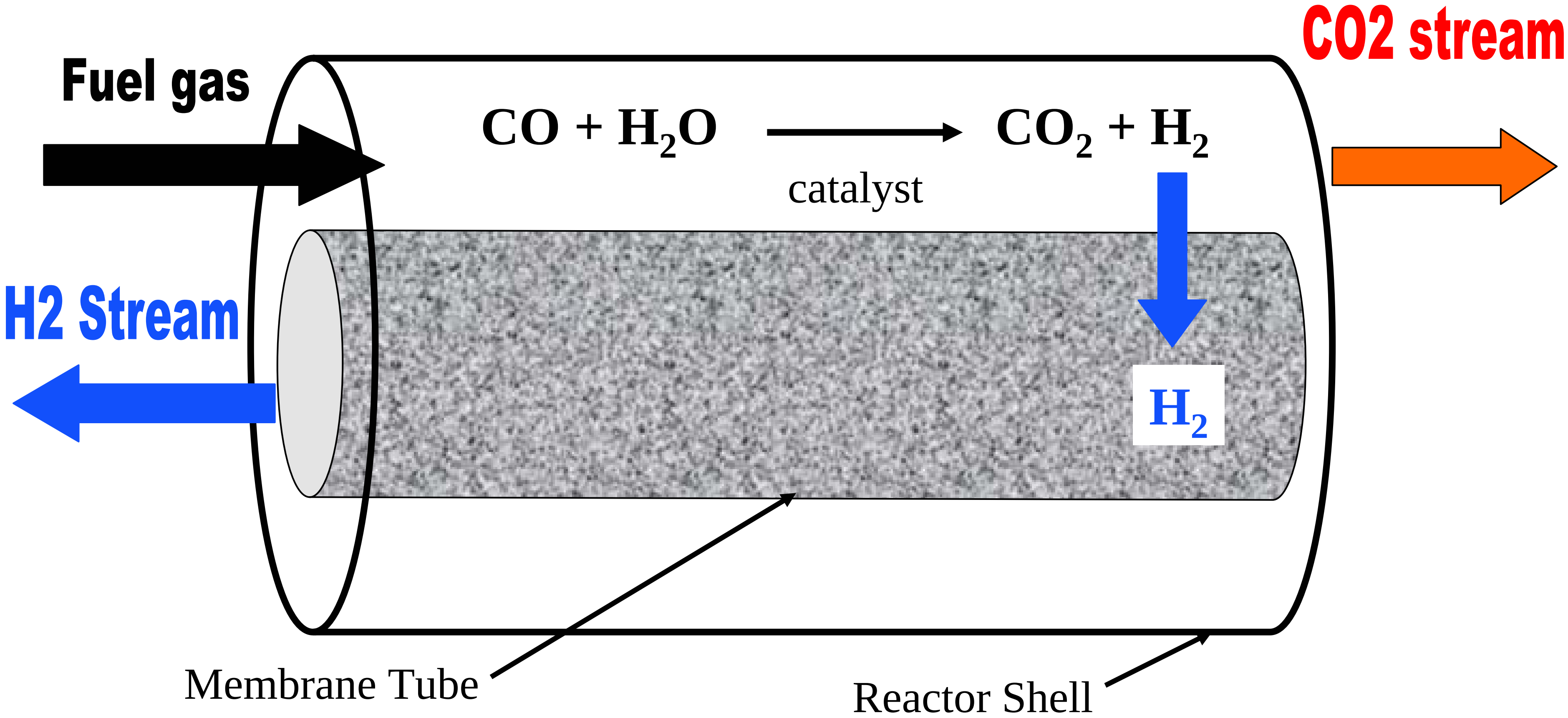
$$\text{Coal} + 3/2\ O_2 \Longrightarrow CO_2 + H_2O$$

  1. Eliminate CO_2 capture system
  2. Simply remove H_2O and compress flue gas



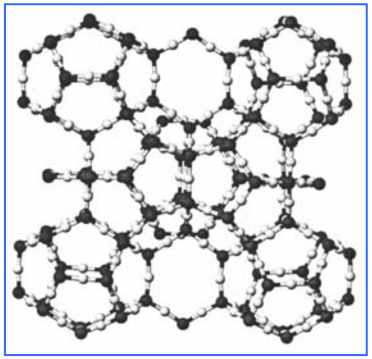
Source: 1. Air Products and Chemicals, Inc. 2002

Water Gas Shift - Hydrogen Separation Membrane Reactor



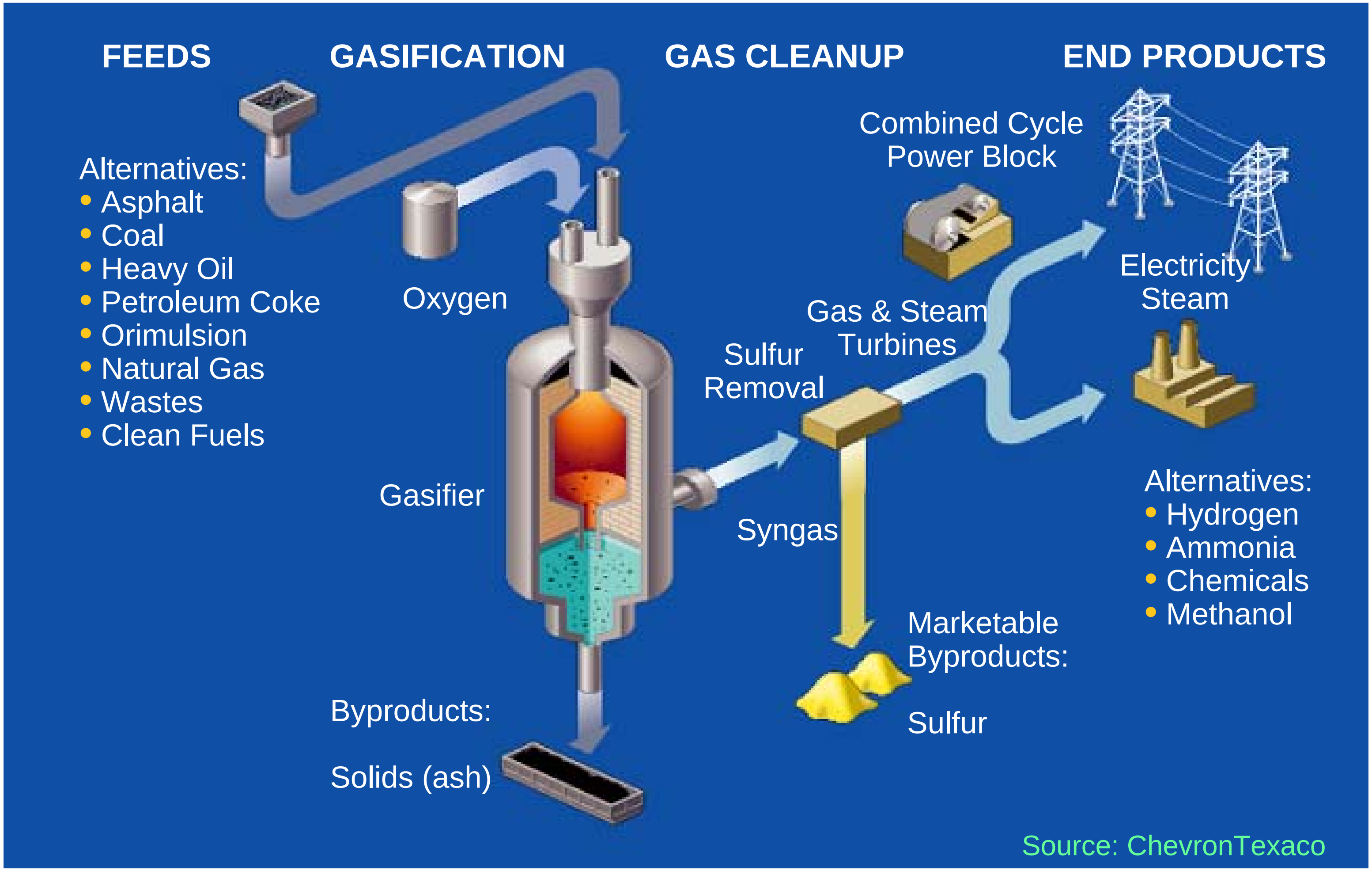
- Removal of hydrogen drives reaction to completion
- Carbon dioxide stream at high pressure, ready for sequestration
- Hydrogen available as a clean energy source

CO_2 Hydrate Formation for Gas Separation

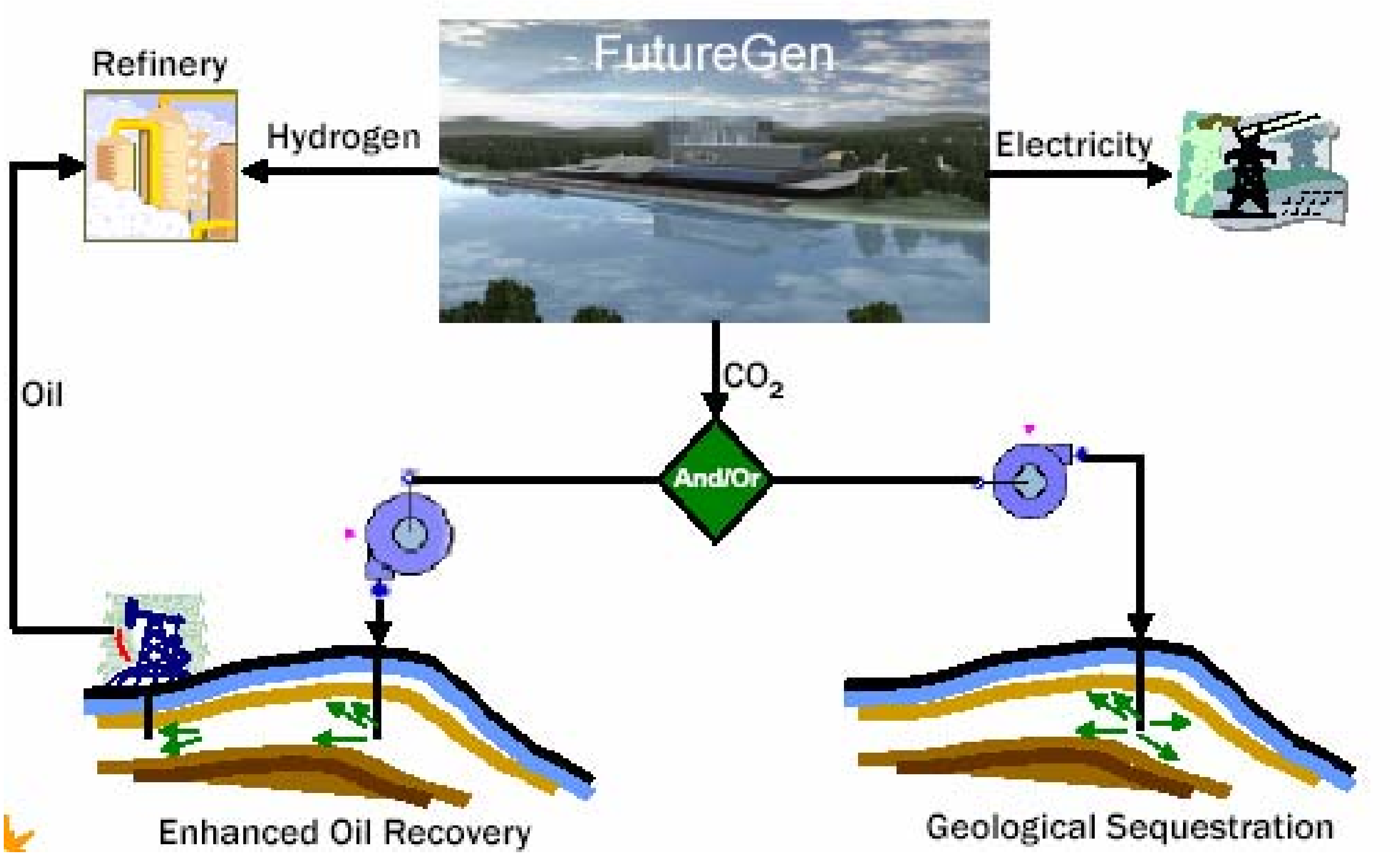


- Forms clathrate by mixing CO_2 in fuel gas stream with chilled, recycled water stream
- Prior work by others predicted poor kinetics and problems with multi-phase flow
  - Results contradict slow kinetics theory – hydrate formation occurs readily with nucleation
  - Multi-phase flow problems will be managed with proper flow velocities and temperature control

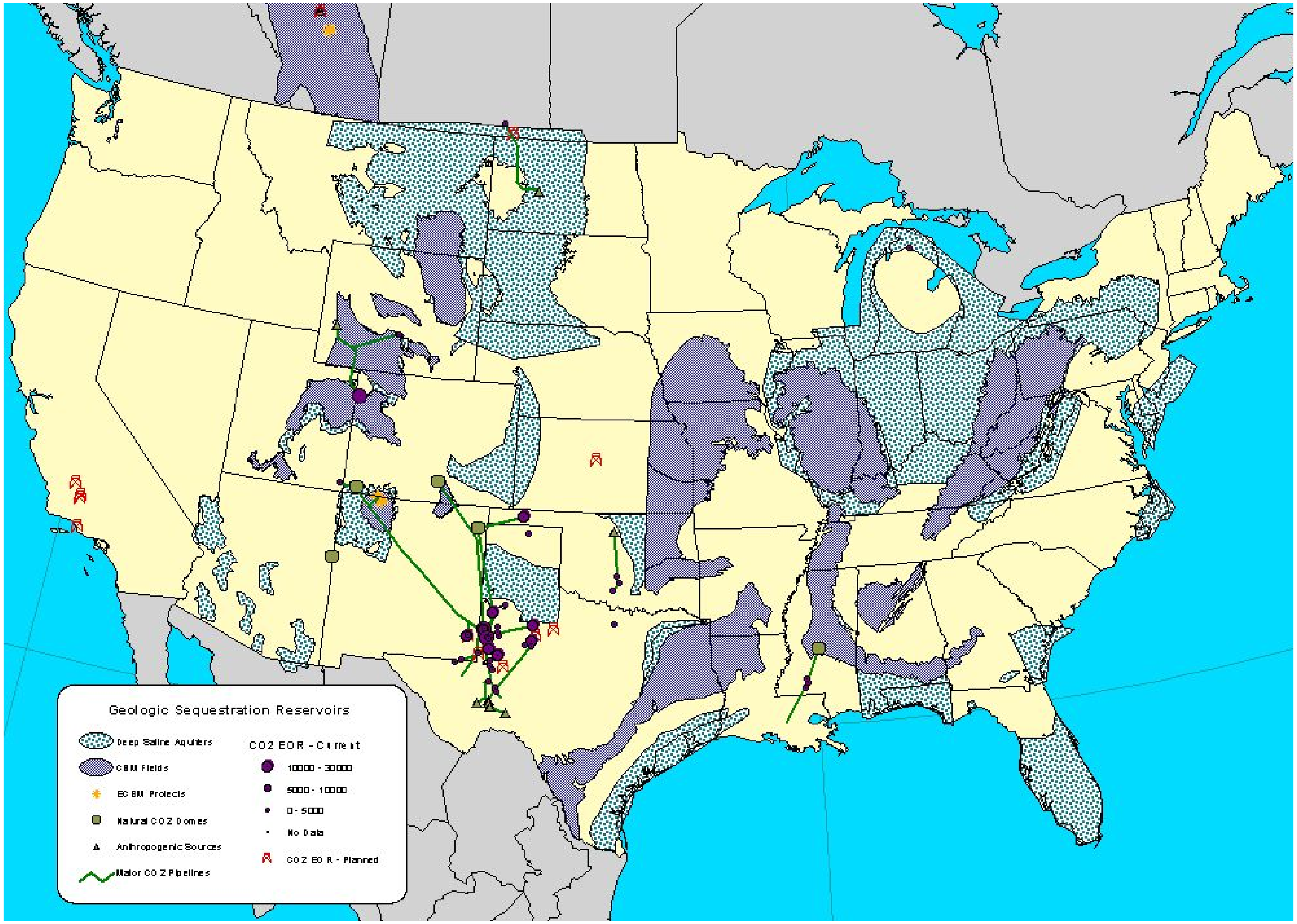
Characteristics of a Gasification Process (Courtesy of ChevronTexaco)



Gasification
Carbon Capture and Sequestration



Geologic Sequestration Options



- Deep Saline Formations
- Deep Coal Seams
- Enhanced Oil Recovery Fields

Geologic Sequestration Highlights
(1 Million TPY CO_2, ~ 100 MW Coal Power Plant)

Weyburn CO_2 EOR Project

- **Pan Canadian Resources**
- **200-mile CO_2 pipeline from Dakota Gasification Plant**
- **130M barrels oil over 20-year project**
- **$28M**

Sleipner North Sea Project

- **Statoil**
- **Currently monitoring CO_2 migration**
- **$80M "incremental cost"**
- **$35/ ton CO_2 tax**

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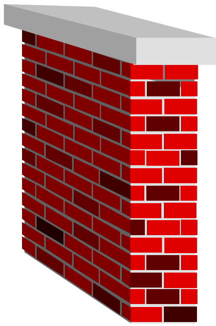
Sequestration R&D

- **Barrier Issues**
  - Health, safety and environmental risks
  - Permanence and large scale verification
  - Capacity evaluation
  - Infrastructure
  - Uncertain regulatory frameworks
  - Protocols for identifying amenable storage sites



- **Pathways**
  - Depleting oil reservoirs
  - Unmineable coal seams
  - Saline formations
  - Enhanced terrestrial uptake
  - Ocean fertilization and injection
  - Regional Partnerships

In Summary

- **Goal: By 2015, a 60 percent efficient, zero emissions, coal-fueled hydrogen and power co-production facility is operational**

- **Benefits:**
  - **Energy security**
  - **Early source of hydrogen for fuel cell vehicles**
  - **Reduced emissions of pollutants and GHGs**

Visit Our NETL Website

www.netl.doe.gov

Visit Our OCES Website

www.netl.doe.gov/coalpower/index.html

Thank You

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Thank you very much for your time; I’m sorry I could not be with you in person today.